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The effect of air-entrainment on concrete containing chert gravel

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THE EFFECT OF AIR-ENTRAINMENT ON CONCRETE CONTAINING CHERT GRAVEL

BY

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A

THESIS

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Approved by V. A. C. Gevecker
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INTRODUCTION

The problem which the writer is analyzing in this paper has been suggested to him by Prof. Carlton of the Civil Engineering Department. It consists of two parts.

1. Bar-Run aggregate is to be obtained from Spring-creek near Rolla. This material is to be screened and re-combined to obtain the best gradation for highest strength concrete obtainable.

2. Durability studies are to be made on the concrete resulting from best established mix by varying the amount of air entrainment compound (Vinsol Resin) to be added to the cement.

Although there has been extensive research made on the effect of air entraining agents on the durability of concrete, the term durability used throughout this paper refers to the resistance of concrete to freezing and thawing, there is not too much information available concerning the effect of in-ferior aggregate on the air-entrained concrete. The only article the writer could find was an article written by Messrs. E. O. Axon, T. F. Willis and F. V. Reagle printed in volume 43 of A.S.T.M. Proceedings, "Effect of Air-Entrapping Portland Cement on the Resistance to Freezing and Thawing of Concrete Containing Inferior Coarse Aggregate." The pro-cedure followed in this paper is very near to the procedure followed in the above mentioned article. Therefore, this article will be referred to many times throughout this paper.

As the second part of the problem is the main object of this paper, the history of air-entrainment in concrete, its advantages and disadvantages should be discussed.

Air-entrainment has been used in actual practice since 1938. During the past few years the use of air-entrainment has been rapidly increasing throughout the country. As of September 1, 1949, some 25 state highway departments were specifying air-entrained concrete for all pavements. One additional state specified air-entrained concrete but permitted its use to be optional with the contractor. Eleven additional states used air-entrained concrete under special provisions for certain projects. Five additional states had used air-entrained concrete experimentally in pavements. Fifteen states specified this type of concrete in structures and three additional states permitted its optional use by the contractor. Nine states used air-entrained concrete under special provisions for bridges or parts of bridges. Eight additional states had used air-entrained concrete experimentally on bridges. Many other large agencies including the War Department, Bureau of Reclamation and Port of New York Authority, required the use of air-entrained concrete almost exclusively.[1]

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(1) Highway Research Board, Current Road Problems, Use of Air-Entrained Concrete in Pavements and Bridges No. 13-R, Revised Edition pp. 18. May, 1950.

Air-entraining materials include:

1. Natural wood resins such as rosin or Vinsol resin.

2. Animal or vegetable fats and oils such as tallow and olive oil and their fatty acids such as stearic and oleic acids.

3. A commercial product known as Ligro which consists largely of oleic resin acids.

4. Various wetting agents such as the alkali salts of sulfated and sulfonated organic compounds.

5. Water soluble soaps of resin acids and animal and vegetable fatty acids.

6. Miscellaneous materials such as the sodium salts of petroleum sulfane acids, etc.[(2)]

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(2) Gonnerman, H. F. Tests of Concretes containing Air-entraining Portland Cements or Air-entraining Materials added to Batch at Mixer. Research Laboratories of the Portland Cement Association. Bulletin 13, pp. 478. April 1, 1947.

The material used in the experiments of this thesis was Vinsol resin. The effect of air-entrainment depends on the percentage of air in the concrete. The effective range is from "3 to 6" percent.[(3)]

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(3) Bauer, Edward E. Plain Concrete. McGraw-Hill Book Co. pp. 219, 1949.

The established fact is that between above mentioned limits air-entrainment is effective against the scaling of concrete and the failure occuring due to successive freezing and thawing cycles which the pavements are subjected to during the year. The concrete is more workable and plastic and there is less segregation. Now there is a need to answer a question. What is the disadvantage of air-entrainment? The experiments and research made on air-entrained concretes show that the reduction in strength and decrease in unit weight is in direct proportion to the increase in air content. There is also a decrease in modulus of elasticity.

In this paper the author will try to add some more data to the extensive studies made on this subject. Today concrete is the most used material in the engineering practice. But we still don't know enough about it to use it most effectively. Air-entrainment is only a small phase of this huge field of studies. The engineer of today is still a puppet of nature. He has to design and build according to his assumptions and only the factor of safety can save his buildings or dams against the forces of nature. The author hopes that the engineer of the future will break the ties that have been binding him for ages and start contributing to the human race at his maximum capacity.

The procedure followed by the author on this paper consists of two parts. First to get a good mix complying with highway standards. This mix will be kept constant throughout the work to see the effects of air-entrainment clearly. The second part of work will be of two phases, first being the effect of air-entraining on the strength of concrete and the second being the effect of it on the durability.

Eight different batches have been poured keeping the mix constant. From each batch three cylinders and three beams have been poured. The cylinders were 6 inches in diameter and 12 inches high. The beams were 16 inches long, $3\frac{1}{2}$ inches wide and $4\frac{1}{2}$ inches deep. The cylinders were tested at 3 days, 7 days, and 28 days in the compression machine for compressive strength, and beams were subjected to freezing and thawing cycles. The author started checking the loss in weight due to freezing and thawing cycles but due to many difficulties and on the suggestion of his advisor Prof. V. A. C. Gevecker decided that the sonic testing of Modulus of Elasticity would give better results and started on testing the beams at five cycle intervals on the sonic testing apparatus.

The following discussions will give the reader a better opportunity to understand the problem. Due to many limitations and many mechanical difficulties encountered during the process of writing the thesis the author would not be able to give the reader the widest aspects of the problem, but he will be happy if he has contributed something to the field he has chosen for his studies.

REVIEW OF LITERATURE

The data to be found on air-entraining and the effect of inferior aggregate on air-entrainment concrete is quite limited. Most of the information available was to be found in A.S.T.M. proceedings starting with the year 1938. A.S.T.M. proceedings contain many articles about the effect of air-entrainment on durability of concrete and about the tests to be made on that subject, but the only article paralleling the author's research was the one suggested to him by Materials Testing Laboratory of Missouri Highway Department. This article has already been mentioned in the introduction part of this paper.

In May, 1947, August, 1947, and in January, 1948, issues of the magazine "Concrete" there are some articles about air-entraining and its use in actual practice.

For the first part of this paper, which is obtaining the best mix complying with highway standards, the writer has used the Portland Cement Association pamphlet "Design and Control of Concrete Mixtures," ninth edition and Edward E. Bauer's Plain Concrete, third edition, 1949, McGraw-Hill Book Company, Inc. has been a great assistance on this part.

The pamphlet written by H. F. Gonnerman and published by Research Laboratories of the Portland Cement Association in April, 1947, "Tests of Concretes Containing Air-entraining Portland Cements or Air-entraining Materials added to Batch of Mixer" also contains very useful information on the subject of air-entraining and the tests to be made to obtain experimental data.

One other pamphlet that has been used as reference in this paper was titled "Use of Air-entrained Concrete in Pavements and Bridges" and published by Highway Research Board in May, 1950, as a part of series concerning the current Road Problems. In this pamphlet air-entrainment, its effects and its merits have been discussed widely referring to A.S.T.M. designation.

The book published by the Engineering Experiment Station of Purdue University titled "A Study of Chert as a Deleterious Constituent in Aggregates" has also been very helpful on the first part of this paper helping the author in his understanding of the gravel used in the experiments.

The Highway Research Board proceedings of 1940, the thesis written by G. F. Hofstaedter on "The Effect of Calcium Chloride on Air-entrained Concrete" and two pamphlets mimeographed by the Civil Engineering Department, one of them being about the use of air-entraining meter and the other being about the use of sonic testing apparatus are also among the literature worth mentioning in this review of literature.

DISCUSSION

This portion of the thesis will contain six parts as follows:

Part 1. Test Apparatus.

Part 2. Obtaining the best mix for the specimens.

Part 3. Pouring of the specimens, their sizes, curing of the specimens.

Part 4. Testing of the specimens at three, seven and twenty-eight day intervals.

Part 5. Freezing and thawing cycles which the beams are subjected to.

Part 6. Sonic testing of the beams for modulus of elasticity.

Test Apparatus

Apparatus used for the experiments were of many different kinds. The list of the apparatus is as follows:

1. Homart Concrete Mixer.
2. Two types of electrical sieve shakers.
3. Hydraulic compression testing machine.
4. The Bowser sub-zero industrial chilling unit and thawing tank.
5. Air-entraining pressure apparatus.
6. Hook gauge to be used for Ohio method of testing the air-entrainment in concrete.
7. Sonic testing apparatus.

To give the reader more information about the apparatus used in the experiments of this thesis the author will take the above mentioned apparatus one by one and give more specific information about them.

1. This mixer is a product of Sears, Roebuck and Co. It is of revolving drum type having a capacity of 3 cu. ft. It is driven by an electrical motor and has a gear ratio of 12 to 1. Therefore, to turn the mixer 20 to 25 revolutions per minute, pulley is rotated 240-300 revolutions per minute. The interior surfaces of the mixer were maintained clean throughout the experiments to keep the mix constant and free of foreign elements. See Figure 1, page 10.

2. Electrical sieve shakers used for screening the gravel were of two types, one being a product of the Gibson Screen Co. having 5 woven wire screens conforming to the standard specification for sieves, sieve designations in inches being 1", 3/4", 1/2", 3/8" and #4 (See Fig. 2, page 10.). The other shaker, a Rotap, was of a smaller size and was manufactured by W. S. Tyler Co. It had a rotary movement. Five sieves having the sieve designations of #8, #16, #30, #50, #100 and one extra sieve to keep them in place was used during the experiments. An iron arm tapped the sieves at intervals to produce settlement of the aggregate (See Figure 3, page 11).

3. The machine used for testing the cylinders for strength was a Hydraulic Compression Testing Machine manufactured by the Riehle Co. It has two ranges on it, one being

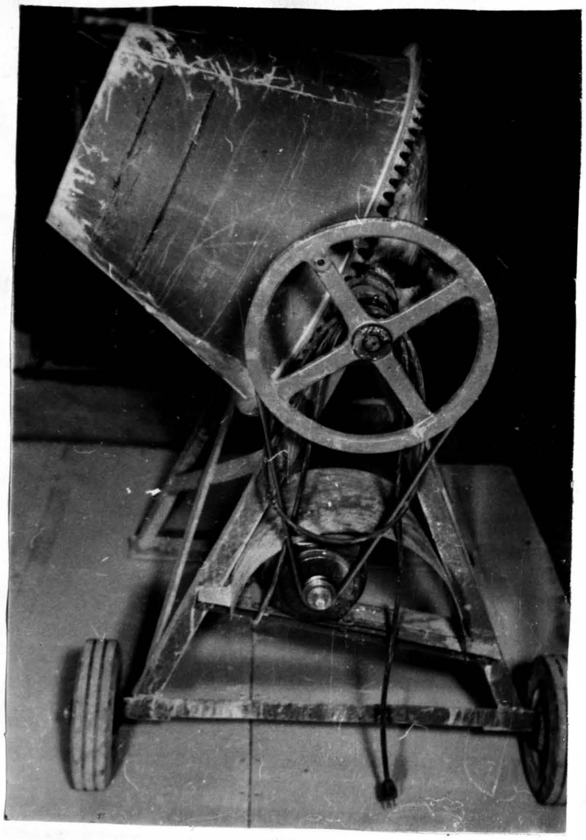

Figure 1. The Homart Concrete Mixer

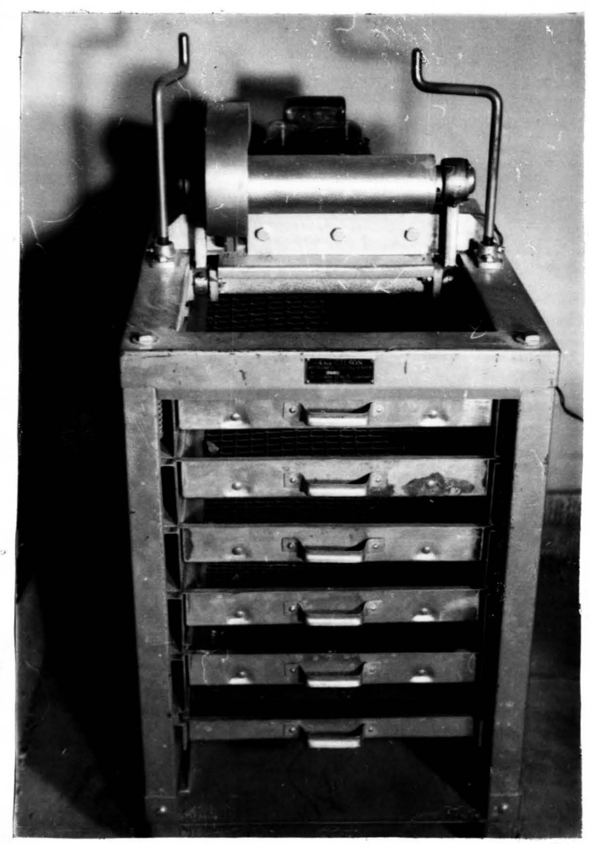

Figure 2. Electrical Sieve Shaker

Figure 3. Rotap

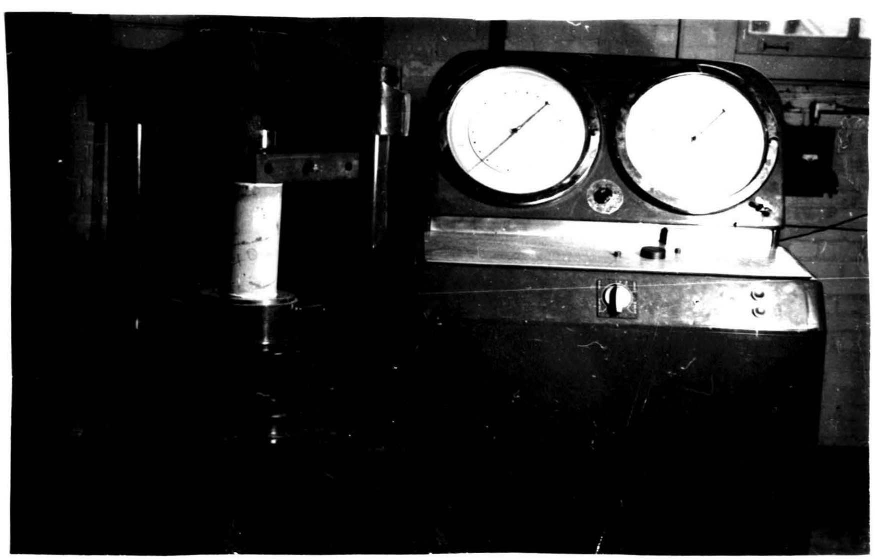

Figure 4. Hydraulic Compression Machine

up to 60,000 lbs. with the smallest division of 100, the other one goes up to 300,000 lbs. with the smallest division being 500. All cylinders had to be centered to avoid any eccentric loading. See Figure 4, page 11.

4. The Bowser Sub-Zero industrial chilling unit was used in obtaining freezing cycles for the beams. It uses Freon 12 as a refrigerant. It has three compartments each having a volume of 8.5 cu. ft. It operates on 110 volts, 60 cycle, single phase power. The required temperature is obtained by adjusting the thermostat. The thawing tank is a metal tank large enough to hold 24 beams in water. A hose was used to circulate the water in the tank. See Figure 5, page 13.

5. The air-entraining pressure apparatus is a portable apparatus made from alkali resistant light weight alloy. It is called the ACME air-entrainment meter, manufactured by E. W. Zimmerman, Chicago, Illinois. It has three movable parts: bowl, upper assembly and calibration cylinder. The test procedure is very simple and the time to make a test is about 5 minutes. Test procedure will be explained in part 3 of discussion. See Figure 6, page 13.

6. A hook gauge was used for testing the air-entrainment in concrete which is above the limits of air-entrainment meter. It is a very simple apparatus consisting of two calibrated rods moving on each other and of a simple hook with a needle point at the end of one of the rods. See Figure 7, page 14.

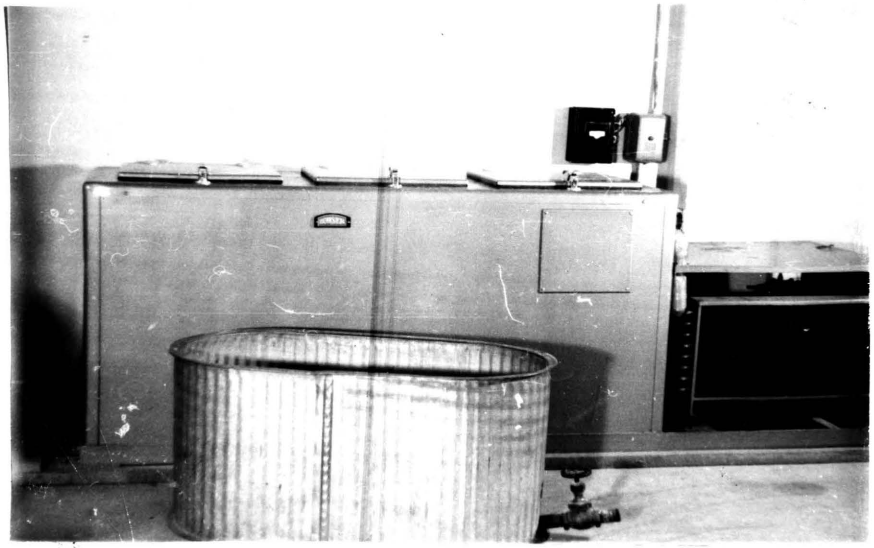

Figure 5. The Bowser Sub-zero Industrial Chilling Unit and Thawing Tank.

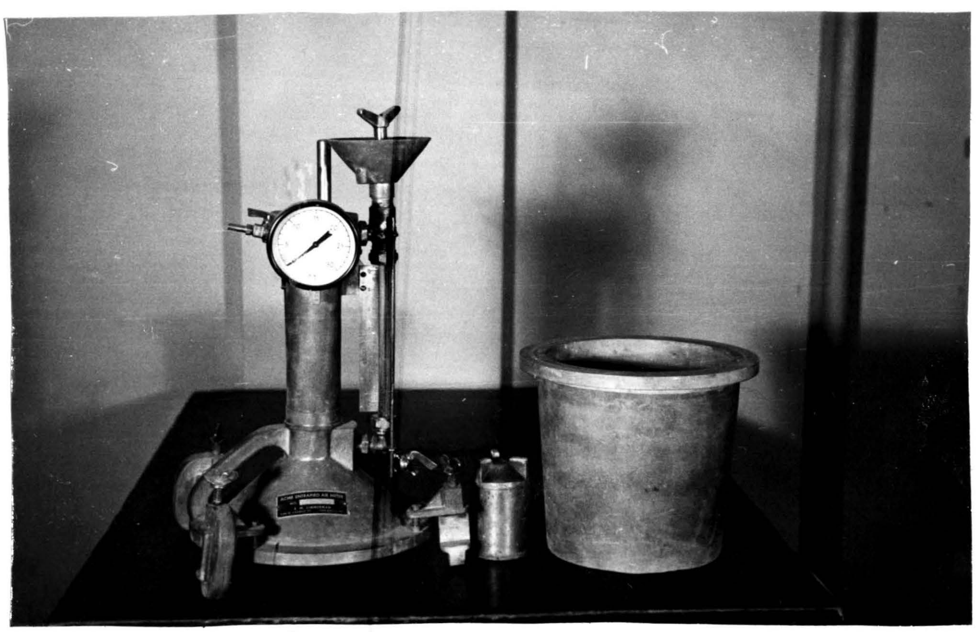

Figure 6. The Air-Entrainment Meter.

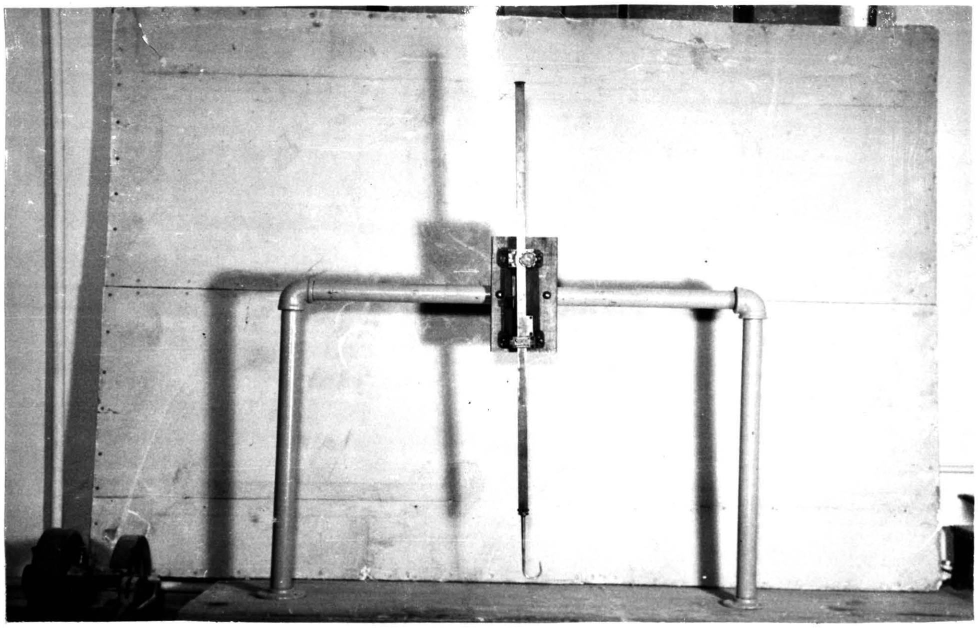

Figure 7. Hook Gauge

Figure 8. Sonic Testing Apparatus

7. The sonic testing apparatus is used to obtain the Young's modulus of elasticity in concrete beams. The apparatus includes an oscillator, support and driver to produce vibration of the specimen and a pick-up and a measuring device to indicate the vibration amplitudes. See Figure 8, page 14.

The apparatus used on the experiment of this thesis consisted of a cathode-ray oscillograph, an audio oscillator, an amplifier,adriver to produce the vibration, and a pick-up.

The cathode-ray oscillograph is a product of the Allen B. DuMont Laboratories, Inc., Passaic, New Jersey, #10020, type 164E. The audio oscillator, #11012 is manufactured by Hewlet Packard, Palo Alto, California. Its range of cycles varies between 600 per second and 6000 per second. The amplifier was an electronic stethoscope, a product of a Feiler Engineering Co., Chicago, Illinois. The driver is an ordinary magnet speaker with a stem cemented to the voice coil which should be on contact with the corner of the beam. The pick-up is a simple phonograph pick-up and is used to deliver the vibrations to the amplifier.

Test procedure of the sonic apparatus will be explained in part 6 of Discussion.

Obtaining The Best Mix

This part of the discussion is set apart for the purpose of showing the procedure followed for obtaining the best mix of concrete which was kept constant throughout the experiment.

Before going into detail the writer finds it necessary to give some information about the gravel used.

The aggregate used in the mix was a Bar-run aggregate obtained from a creek near Rolla, as is mentioned in the introduction part of this paper. The type of the aggregate was chert.

Chert may be classified as a sedimentary rock composed predominately of silica with an aphanatic or very fine texture.[4]

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(4) Sweet, Harold S., A Study of Chert as a Deleterious Constituent in Aggregates, The Engineering Experiment Station of Purdue University Research series, pp. 13, September, 1942.

Chert is a deleterious constituent in concrete aggregates. It causes popouts on the surface and gives a lower flexural strength. Because of the above mentioned qualities of chert its use has been limited in actual practice. Many failures in bridges, highway pavements and concrete runways, especially in northern sections of the country where weathering conditions are rough, have been due to the aggregate containing chert in it.

Although the aggregate used in the experiments of this paper was chert, its disadvantageous qualities were not very noticeable. The only explanation the writer could find is that the aggregate was completely dried so that no water was in the material prior to mixing. Although the aggregate was obtained in December of 1951, actual handling of the aggregate for experiments started in November, 1952. During that ten months, aggregate was kept in a box in the laboratory where the temperature was about 70° F. Because of this, the aggregate was completely dry and the tests made for this purpose showed the water content as 0.

The first thing done on aggregate was to get a gradation of aggregate using a sieve analysis. The standard sieves used for this purpose are numbers 4, 8, 16, 30, 50 and 100 for fine aggregate and 1", 3/4", 3/8" and No. 4 for coarse aggregate. The results gave the fineness modulus of aggregate which is a term used as an index of the fineness or coarseness of aggregate. It is the summation of the cumulative percentages of the material, retained on the standard sieves divided by 100.[(5)] Results are as shown in Table 1, page 18.

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(5) Portland Cement Association pamphlet, Design and Control of Concrete Mixtures, Ninth edition, pp. 13.

These fineness moduli are a little erratic because of the absence of 1½" sieve in the laboratory. In its place 1" sieve has been used. According to Edward E. Bauer sieves should number 100, 50, 30, 16, 8, 4 and 3/8", 3/4" and 1½" sieves of the U. S. Series.(6)

(6) Bauer, Edward E., Plain Concrete. Third Edition, New York, McGraw-Hill, pp. 99. 1949.

Table 1

Sieve Analysis Values

Sieves	Total Percentages Retained	
	Sand	Pebbles
1"	0	15
3/4"	0	23
3/8"	0	55
No. 4	0	100
No. 8	37	100
No. 16	55	100
No. 30	65	100
No. 50	90	100
No. 100	100	100
	3.47	6.93

The problem after that was to decide the best gradation which would give the strongest concrete. For that purpose again Portland Cement Association's pamphlet "Design and Control of Concrete Mixtures" and Edward E. Bauer's "Plain Concrete" book were used as reference. With the help of Mr. C. D. Muir of the Civil Engineering Department the writer decided on a gradation giving the densest mix. This gradation is as follows.

Coarse Aggregate

Sieve Sizes	Per Cent Retained (Cumulative)
1"	0
3/4"	5
1/2"	30
3/8"	75
#4	100

Fine Aggregate

Sieve Sizes	Per Cent Retained (Cumulative)
#8	15
#16	30
#30	60
#50	90
#100	100

After the gradation problem was decided, the thing to be determined was the maximum size of coarse aggregate.

"The maximum size of aggregate is designated as the smallest sieve having a value between 0 and 15 percent retained."[7]

(7) Ibid.

Considering the size of the specimens to be obtained it was decided to choose 3/4" as the maximum size of the coarse aggregate.

To decide the percentages of fine and coarse aggregate in total, unit weights of combinations of fine and coarse aggregate were determined. This was done by plotting a curve with percentage sand against unit weight in lbs./cu. ft. The sand percentage giving the biggest unit weight was picked up as the ideal percentage.

Test procedure is as follows:

1. The mixture of 30 percent fine aggregate and 70 percent coarse aggregate was picked up as the starting point. Forty-four lbs. of coarse aggregate and 18.9 lbs. of fine aggregate were mixed and put into a 0.5 cu. ft. measure in three layers, each layer being tapped 25 times evenly over the

surface with a rod. After the measure was filled up to the top with gravel it was weighed. The weight excluding the weight of can was 53.1 lbs. Dividing the weight by 0.5 cu. ft., the unit weight was obtained. The value was 106.2 lbs./ cu. ft.

2. In the second case 44 lbs. of coarse aggregate and 29.4 of fine aggregate were mixed giving 40 percent fine aggregate and 60 percent coarse aggregate. The same procedure was followed and the value obtained for unit weight was $\frac{55}{0.5}$ = 110 lbs./cu. ft.

3. The same procedure was followed for 50 percent fine and 50 percent coarse aggregate using 44 lbs. of coarse and 44 lbs. fine aggregate. Unit weight was $\frac{56.5}{0.5}$ = 113 lbs./ cu. ft.

4. In the fourth part 60 percent fine and 40 percent coarse were mixed, weights being 66 lbs. for fine aggregate and 44 lbs. for coarse aggregate. Unit weight was $\frac{55.5}{0.5}$ = 111 lbs./cu. ft.

The curve was plotted with four points obtained above and 50 percent fine aggregate and 50 percent coarse aggregate was picked as the best combination from the graph. See Figure 9, page 21.

The first batch was poured with the following quantities:

Water = 15 lbs.

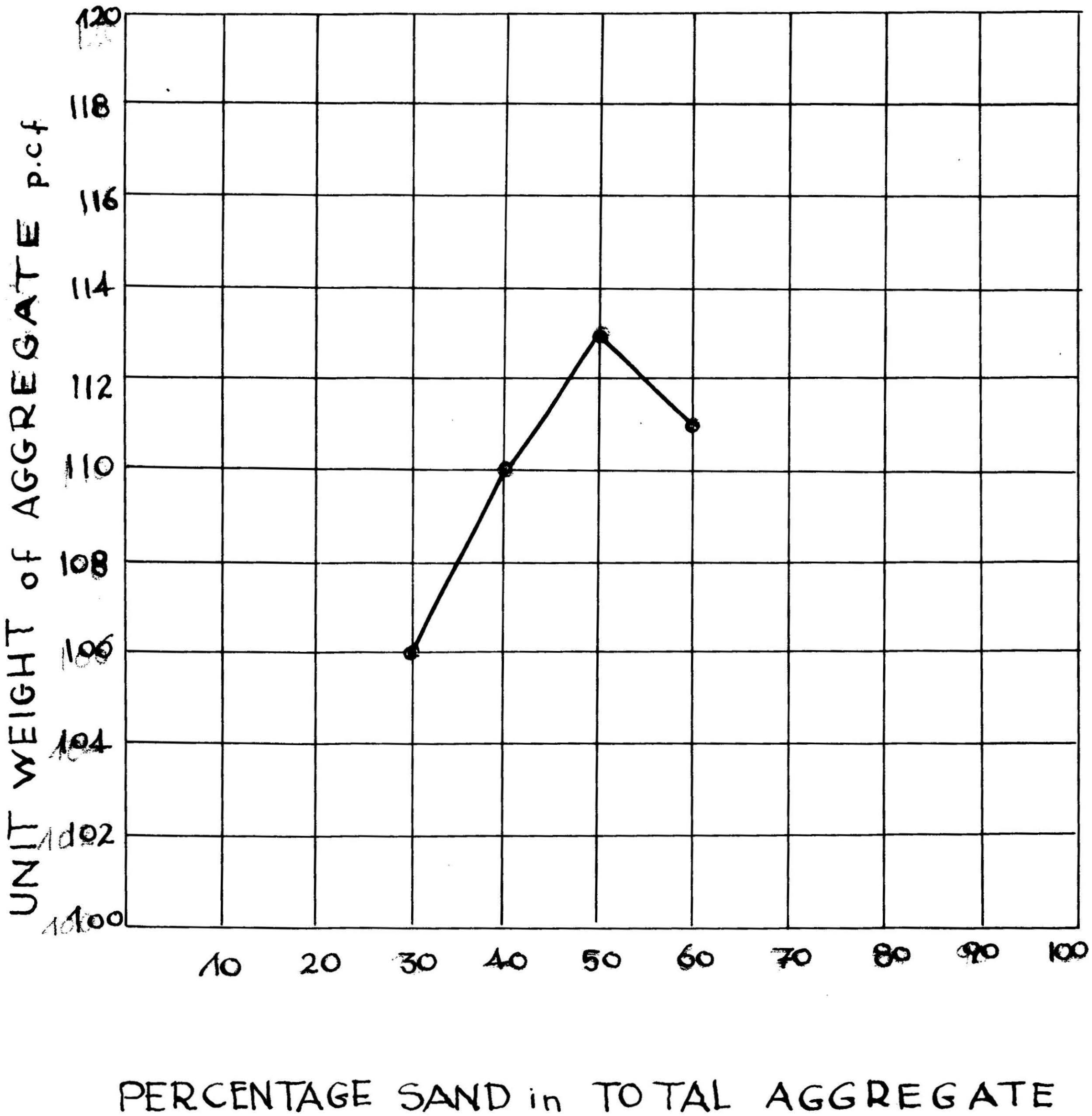
Sand = 67.5 lbs.

Gravel = 67.5 lbs.

Cement = 30 lbs.

Figure 9

CURVE SHOWING the RELATIONSHIP BETWEEN UNIT WEIGHT of AGGREGATE and PERCENTAGE of SAND



The above mix was picked out from the table giving trial mixes for concretes of medium consistency (3-in. slump) from the pamphlet published by Portland Cement Association "Design and Control of Concrete Mixtures." The result was stiff concrete with a very small slump.

After considering the dryness of aggregate it was decided to use more water in the mix. The second batch was poured using 20 lbs. of water keeping the other quantities constant. The concrete of this mix was of a more plastic nature having a slump of 4.5 in. The first specimens including 3 cylinders and 3 beams were poured from that batch and put in the moist room and were kept there for three days. At the end of 3 days one of the cylinders was capped and tested in the Riehle compression machine. The strength was 1600 psi. which being about 60 percent of 28 day strength showed that the concrete was a poor concrete.

The third batch was poured with 0.5 lbs. less water. Slump was 3 in. Test specimens were poured and one of the cylinders was tested for strength at the end of 3 days. The result was 2030 psi. This result showed that the concrete of the third batch was a fairly good concrete complying with the Highway Standards, having a slump of 3 inches and a strength of about 3000 psi.

Pouring of the Specimens, Their Sizes, Curing of the Specimens

This part will include the pouring of the specimens, their sizes and the curing period. As it was explained in the preceding part, the best mix was obtained.

The materials were weighed and put into the batch mixer and the mixing was started. Water was added last. Mixing period was 2 minutes and was measured from the time all solid materials were in the mixer drum. Because of the mixer being tilting type, pouring was easy. The concrete was poured into a clean pan and was hand mixed to prevent segregation. Slump test was made and the concrete was put into forms in three layers, each layer being tapped 25 times with a tamping rod. The above procedure has been followed for pouring of all the specimens.

The forms used throughout the experiments were of two kinds, wooden forms and cardboard cylinders. Wooden forms were of prismatic shape, inside dimensions being 16 in., 4.5 in and 3.5 in. They were oiled before the concrete was put in. Cardboard cylinders were 12 in. high and 6 in. in diameter. From each batch three beams and three cylinders were poured. See Figure 10, page 24.

The forms after concrete was poured were put in the moist room. After one day they were removed. Beams and cylinders were kept in the moist room until day before testing.

Cylinders were tested at the end of 3, 7 and 28 days. They were capped with plaster of paris before testing.

Figure 10. Cylinders and Beams

Vinsol resin was added to the second batch to produce air-entrainment in the concrete. Vinsol resin was obtained in powder form and was used in a 3 percent sodium hydroxide solution, the rate being 1 g. of powder per 10 ml. of solution.[8]

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(8) Bauer, op. cit., pp. 81.

The solution obtained was weakened to 1/10 of the original strength by adding distilled water.

The next thing to be decided was the use of the solution to obtain required amount of air entrainment. For that again Edward E. Bauer's "Plain Concrete" was used as reference. According to that book, the amount of Vinsol Resin powder needed for average conditions to produce 3 to 5 percent air in the concrete is 0.01 percent by weight of cement.[9]

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(9) Ibid.

To verify this theory the writer decided to pour some trial batches adding different amounts of vinsol resin in each batch. The amount of materials used for those trial batches are as follows:

Coarse aggregates = 15 lbs.

Fine aggregate = 15 lbs.

Cement = 6.7 lbs.

Water = 4.5 lbs.

The amount of vinsol resin solution was decided according to the above mentioned theory, the weight of the crystals to be used being 0.01 percent of the weight of cement. Therefore, the weight of crystals was 6.8 x 0.0001 = 0.00068 lbs. At 454 g. per lb., the weight of crystals was 0.31 g. If 1 g. of the crystals are dissolved in 100 ml. of the vinsol resin solution, the amount of solution needed was 100 x 0.31 = 31 ml. According to Bauer this amount of vinsol resin solution would give between 3 and 5 percent of air in concrete. The limits for air-entrainment in this paper were selected to be between 1 percent and 9 percent. It was decided to use increments of this 10 ml. of vinsol resin solution for each trialmix to obtain air in the concrete.

The materials were mixed and 10 ml. of vinsol resin solution was added during the mixing period. An air-entrainment meter was used to test the concrete for the percentage of air in concrete. Before this was done the apparatus was calibrated and an aggregate correction factor which shows the percentage of air in aggregate used was determined.

Calibration of pressure apparatus is as follows:

1. The volume of calibration cylinder was obtained by weighing it empty. Then it was filled with water at 70° F. and was weighed to the nearest 0.5 gms. The difference between two weights was divided by 0.998. Thus the volume, v, was obtained in milliliters.

2. The volume of the measuring bowl of the apparatus was determined as above except the weight was measured to the nearest 0.01 lbs. This was divided by 62.31 to get the volume, V, in cu. ft.

3. The equation used for R, proportion between the volume of calibration cylinder and the volume of measuring bowl, was:

$$R = 0.003531 \frac{v \text{ (in milliliters)}}{V \text{ (in cu. ft.)}}$$

4. The expansion factor D was obtained from the scale as the difference between arrow reading and the zero mark on the scale.

5. The calibration factor K was obtained measuring the water column depressed during the calibration procedure to obtain the gage pressure required to make the scale graduations correspond directly to the percentage of air introduced into the indicator bowl by the calibration cylinder when the bowl was level full of water. The test was started at the arrow. Therefore K is equal to 0.98R.

The calibration test to determine the operating pressure is as follows:

1. The calibration cylinder was placed in the bowl in such a way that the water could not enter the bowl.

2. Apparatus was filled with water to a point just above the arrow and 8 psi. pressure was applied.

3. The apparatus was tilted about 30 degrees from vertical and was rolled while tapping to remove entrapped air.

4. The apparatus was brought to vertical position. The pressure was released gradually and the water was let off until it was on the level with the arrow.

5. Air pressure was applied until the reading on the

scale was about K which is the calibration factor.

6. The sides of the bowl were tapped lightly until the scale was read at exactly K. The pressure gage was read to obtain Pc which is the pressure.

7. The pressure was gradually released.

8. The procedure was repeated from step 5 on to check the reading.

9. The operating pressure P was obtained subtracting 0.10 from Pc which is the theoretical correction to allow for the difference between distributing air in fresh concrete and in the calibration cylinder[(10)].

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(10) Pamphlet mimeographed by Civil Engineering Department. "Use of the Pressure Apparatus for Measuring the Percent of Air-Entrained Concrete."

Data:

Wt. of empty bowl = 8.57 lbs.

Wt. of bowl filled with water = 21.18 lbs.

$$\text{Volume} = \frac{21.18 - 8.57}{62.31} = 0.203 \text{ cu. ft.}$$

Wt. of empty calibration cylinder = 779.2 grams

Wt. of cylinder filled with water = 1004.5 grams

$$\text{Volume} = \frac{1004.5 - 779.2}{0.998} = 225.5 \text{ milliliters}$$

Calibration:

$$R = 0.003531 \times \frac{225.5}{0.203} = 3.92$$

$$K = 0.98 \times 3.92 = 3.82$$

$$Pc = 15.1 \text{ psi.}$$

$$P = Pc - 0.10 = 15.0 \text{ psi.}$$

Therefore, the percent of entrained air was read on the water column when 15 psi. pressure was applied.

For determination of aggregate factor.

1. Exact amount of fine and coarse aggregate required to make enough concrete to fill the bowl was measured.

2. The bowl was filled half full with water and aggregate was placed in the bowl.

3. Water was filled to a point a little above the arrow. Eight psi. pressure was applied to remove any entrapped air. Pressure was released and water was let off until the water level was on the arrow.

4. Fifteen psi. pressure was applied and the gage was read to the nearest $\frac{1}{2}$ division. The h_1 value was obtained in this way.

5. Air was released and the scale was read again giving the h_2 value.

6. By subtracting h_2 value from h_1 aggregate correction factor A_2 was obtained.

Data:

$h_1 = 2.0$

$h_2 = 0.0$

Therefore the aggregate correction factor $A_2 = h_1 - h_2 = 2.00 - 0.00 = 2.00$

The value obtained was of a greater value than the value obtained in the tests of the above mentioned pamphlet. The only explanation for this the writer could find is that the aggregates were completely dry. The moisture in the aggregate was replaced by air during 10 month period during which aggregate was kept under 70^{o} F. in the laboratory.

After obtaining aggregate correction factor, the procedure followed for determination of the Entrained air in concrete is explained below.

1. Concrete was placed in the bowl in three layers. Each layer was rodded 25 times.

2. The same procedure as used above for determining the aggregate correction factor was followed.

3. Air content A_1 was obtained as the difference between $h_1 - h_2$.

4. The percentage of air entrained was obtained by subtracting aggregate correction factor A_2 from A_1.

Data:

$h_1 = 2.7$

$h_2 = 0.0$

$A_1 = h_1 - h_2 = 2.70 - 0.0 = 2.7$

$A = A_1 - A_2 = 2.7 - 2.0 = 0.7$ lbs.

Five different trial batches following the above procedure were poured adding 10, 15, 20 and 30 milliliters of vinsol resin solution to each trial mix. The results are as follows:

Vinsol resin solution (m.l.)	Percent air in concrete
10	0.7
15	1.5
20	2.0
30	5.2

Using the above results as reference, the second batch was poured. The quantities used for the second batch are as follows.

Coarse aggregate = 60 lbs.

Fine aggregate = 60 lbs.

Cement = 27.3 lbs.

Water = 17.8 lbs.

Vinsol resin = 40 ml.

The other batches were poured using the same quantities of aggregate, water and cement adding 60, 80, 100 and 120 milliliters of vinsol resin solution. The results will be shown in Table 2, page 33. With 120 milliliters of vinsol resin solution the air entrainment obtained was 5.4 milliliters which was close to the limit that the air-entrainment meter would show. For that reason the need for using some other method was obvious.

There were two methods almost similar to each other to choose from. One was Indiana method and the other was Ohio method which is a modification of Indiana method. The second method, being easier than the first one, was used.

The apparatus used for Ohio method consisted of a hook gauge and a container. The procedure followed was similar to Bauer's procedure in his book "Plain Concrete."

First the container was calibrated in the following way.

1. Weight of container full of water = 55.3 lbs.
2. Weight of empty container = 24.0 lbs.
3. Weight of water in container = 31.3 lbs.
4. The volume of container (31.3/62.36) = 0.50 cu. ft.

The batch was mixed and 154 milliliters of vinsol resin solution was added to the batch and the unit weight of concrete was obtained with the following procedure.

5. Weight of container full of concrete = 91.0 lbs.

6. Weight of empty container = 24.0 lbs.

7. Weight of concrete in container = 67.0 lbs.

8. Unit weight (actual) of concrete (67/0.5) = 134 lbs./ cu. ft.

In the third step the air content was found.

9. Calculated weight of 1/8 cu. ft. of concrete ($\frac{1}{8}$ x 134) = 16.8 lbs.

10. Weight of empty container = 24.0

11. Weight of container and 1/8 cu. ft. of concrete = 40.8

12. The amount of water added to replace the water taken by concrete (hook gauge was used for this purpose) = 270 ml.

$$A\% = \frac{\text{Vol. of Water added ml.} \times 0.00003531 \text{ ml./cu. ft.}}{0.125} \times 100$$

$$A\% = \frac{270 \times 0.00003531}{0.125} \times 100 = 7.6$$

The same procedure was followed with 176 milliliters of vinsol resin solution and the amount of water added was obtained as 332 milliliters. Air content was found with the above formula.

$$\text{Air Content} = A\% = \frac{332 \times 0.00003531}{0.125} \times 100 = 9.4$$

The results obtained with air-entrainment meter and by the Ohio method were plotted resulting in an almost smooth curve (see Figure 11, page 34).

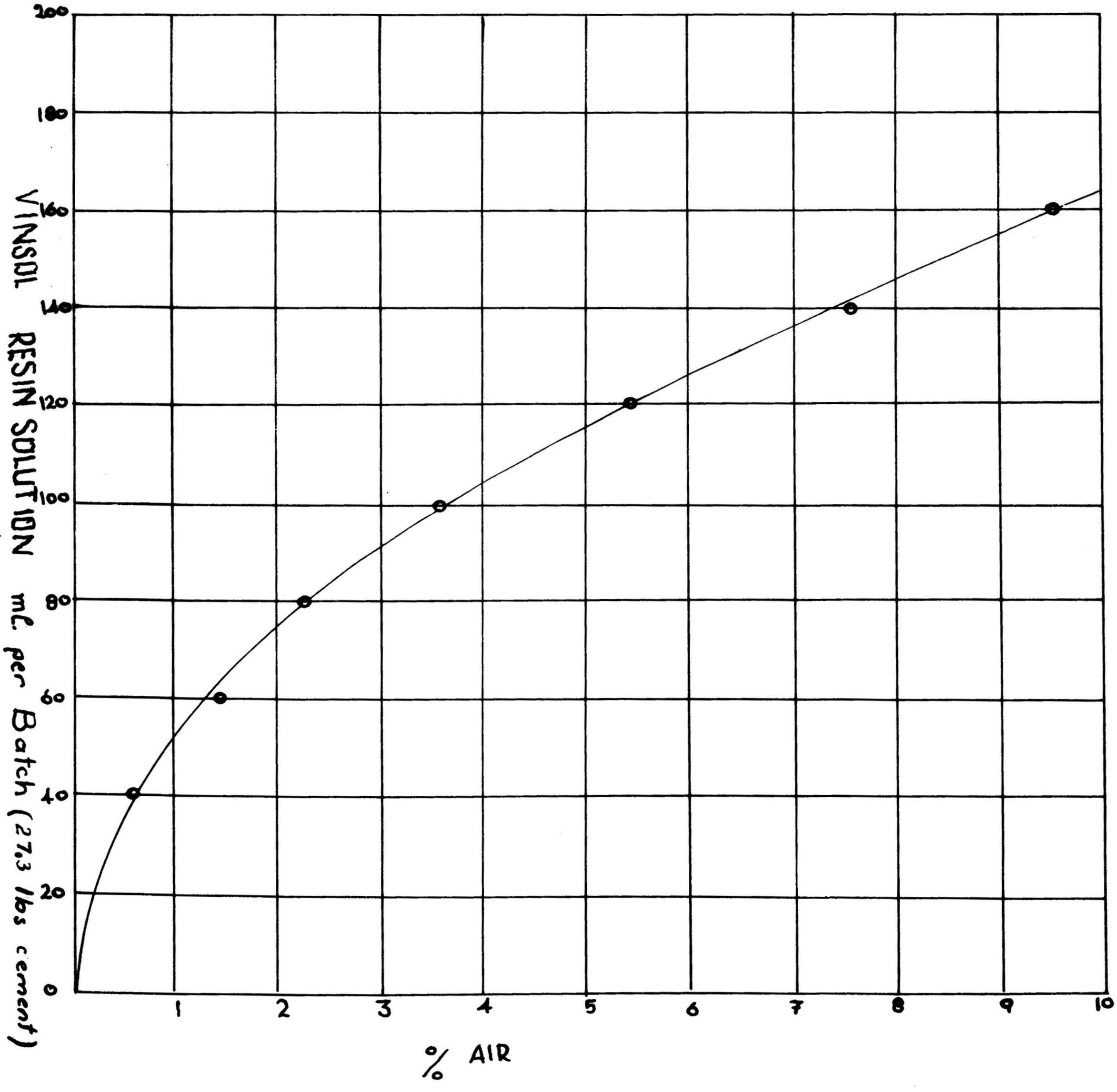
Table 2

Amount of Materials Used in Each Mix

Mix No.	W/C Ratio by weight	Cement lbs.	Sand lbs.	Gravel lbs.	Vinsol Resin Solution Milliliters	Percent Air
1	0.650	27.3	60.0	60.0	0	0.0
2	0.650	27.3	60.0	60.0	40	0.6
3	0.650	27.3	60.0	60.0	60	1.5
4	0.650	27.3	60.0	60.0	80	2.2
5	0.650	27.3	60.0	60.0	100	3.5
6	0.650	27.3	60.0	60.0	120	5.4
7	0.650	30.0	66.0	66.0	154	7.6
8	0.650	30.0	66.0	66.0	176	9.4

Figure 11.

AIRENTRAINMENT CURVE - AMOUNT OF VINSOL RESIN SOLUTION VS. % AIR ENTRAINMENT



Testing of the Specimens at 3, 7 and 28 Day Intervals

This part of the discussion will be about testing of the cylinders at the end of 3, 7 and 28 days. As was mentioned in the third part, all the specimens were kept in the moist room until they were due for testing.

Cylinders to be tested were taken one day before the test day and were capped using plaster of paris. Capped cylinders were left in room temperature to dry the caps, then they were taken to the laboratories of the Mechanics Department and were tested for compressive strength in the Riehle Compression Machine (See Figure 12, page 37). The load was applied continuously and without shock. During the application of the first half of the load a faster rate of loading was permitted.

The compressive strengths of the specimens were calculated by dividing the maximum load carried by the specimen during the test by the average cross-sectional area which was 28.3 in. and was expressed to the nearest 10 psi.

The results will be shown in Table 3, page 36, and in Figure 13, page 38.

Table 3

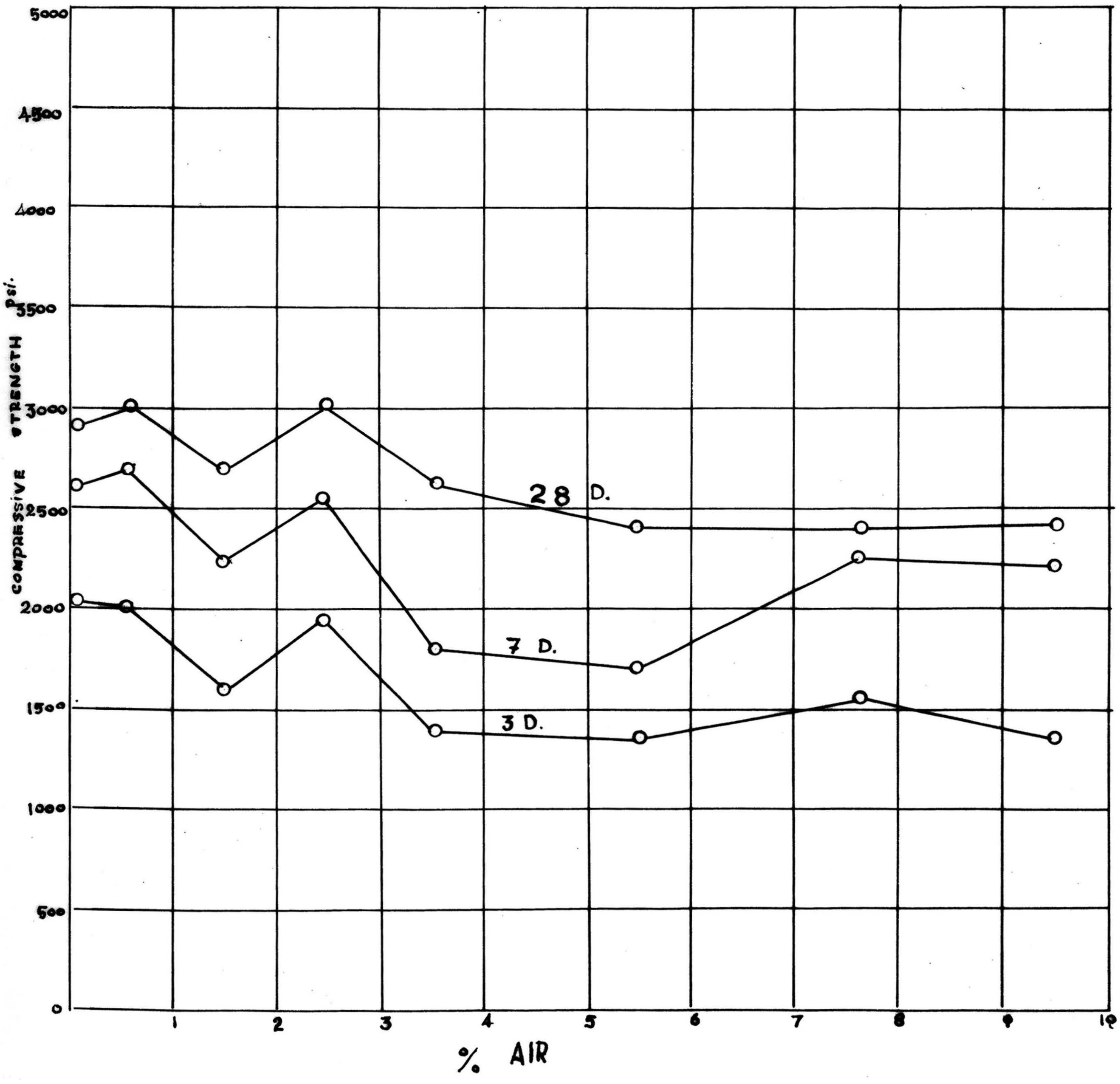
Test Results of 3, 7, 28 Days Compressive Strength Tests

Mix No.	W/C Ratio by weight	Average Compressive Stress, psi.		
		3 Days	7 Days	28 Days
1	0.650	2030	2620	2920
2	0.650	2000	2700	3000
3	0.650	1590	2280	2700
4	0.650	1960	2550	3010
5	0.650	1400	1800	2640
6	0.650	1350	1700	2420
7	0.650	1530	2260	2400
8	0.650	1350	2230	2370

Figure 12. Testing of the Cylinders in the Riehle Compression Machine and the Typical Failure of a Compression Cylinder.

Figure 13.

COMPARISON CURVE - COMPRESSIVE STRENGTH VS. % AIR ENTRAINMENT at 3, 7 and 28 DAYS



Freezing and Thawing Cycles Which The Beams Are Subjected To

In this part of the discussion the procedure followed for freezing and thawing of the concrete beams will be discussed.

The problem the writer encountered in this phase of the work was what cycle of freezing and thawing to use. Investigators have been using various kinds of cycles. Every book on this subject gives a different cycle. As an example the author would like to list some of the cycles he encountered.

Portland Cement Association's procedure for freezing and thawing is freezing the specimens in water in rubber containers slightly larger than the specimens. Containers are placed in a brine solution which is maintained at 10 to 20 F. average freezing period being 55 min. Specimens are thawed by removing the containers from the brine and placing in a tank containing water at 80 F., which is decreased to 60 F. in 1 hour and maintained at this temperature. The thawing period is 3 hours and 5 minutes. A complete cycle requires 4 hours.[(11)]

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(11) Axon, E. O., Willis, T. F. and Reagel, F. V. Effect of Air Entrapping Portland Cement on the Resistance to Freezing and Thawing of Concrete Containing Inferior Coarse Aggregate, American Society for Testing Materials Proceedings Vol. 43, 1943, pp. 987.

In Missouri Procedure Specimens are frozen in the air of a cold room for 10 hours. The temperature of the room is maintained at 0 F. Thawing is done by placing the specimens in water at 40 F. for 2 hours. A complete cycle is 12 hours.(12)

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(12) Ibid.

Another procedure is to keep the specimens 18 hours in freezer at 10 F. for freezing. For thawing they are kept in water at a temperature of 40 ±2 F. for 6 hours.(13)

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(13) Withey, M. O. Consideration Involved in the Making of Freezing and Thawing Tests on Concrete, American Society for Testing Materials Proceedings Vol. 46. 1946 pp. 1204.

The writer referring to other articles on the subject decided to use a 2 hour freezing and a 2 hour thawing cycle. During the freezing period the temperature in the freezer was set -10 F. and for thawing the temperature of the water was kept at 60 F. by running water.

Twenty-four beams were subjected to freezing and thawing. There were 3 beams of each batch and 8 batches were poured, each batch having a different air percentage.

Beams were kept in the moist room for 28 days before cycles started. At the end of 28 days they were taken out and were dried. Then they were put in the water tank for 2 hours. At the end of 2 hours they were put in the freezing machine, 8 beams to each compartment of the machine, and were kept there for 2 hours. See Figure 14, page 41.

In a day 5 cycles were obtained. At the end of 10 cycles the freezing machine got out of order. In 15 days it was

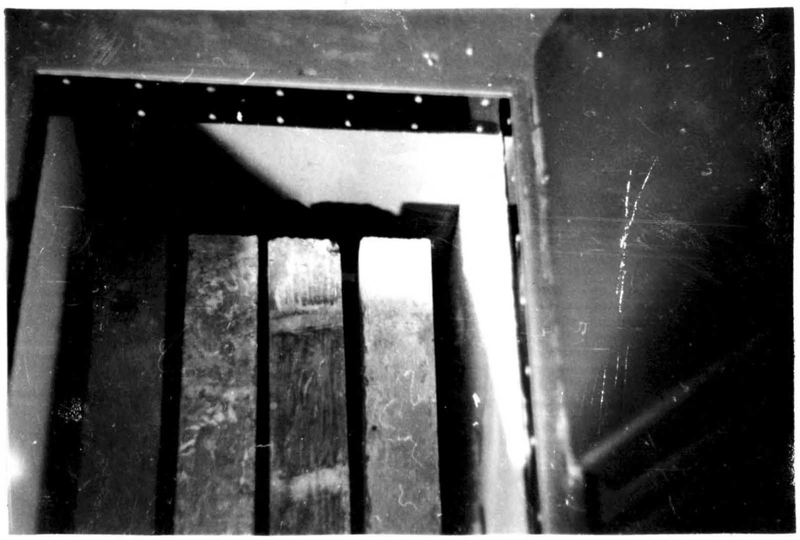

Figure 14. Beams in the Freezing Unit

repaired and cycles started again, but the efficiency of the machine was lessened. An average of 10 hours was needed to obtain -10 F. Because of this it was decided to lengthen the freezing period from 2 hours to 10 hours. Thawing period was kept 2 hours. Forty cycles were obtained in that way. At the end of 40 cycles there was still no apparent deterioration on the beams.

Sonic Testing of the Beams for Modulus of Elasticity

Before starting the freezing and thawing cycles, the beams were weighed. The weights were recorded and it was decided to use the loss of weight method as an index of deterioration. Beams were weighed at the end of 20 cycles. The results obtained were discouraging. Instead of a loss there was a small gain in weight of every beam. The problem was considered again and the use of sonic testing for Young's modulus of elasticity was found as the best solution.

The dynamic method of measuring Young's modulus of elasticity of the concrete beam is based upon the determination of the natural frequency of vibration, the weight and the dimensions of the specimen.

There are two fundamental formulas which can be found in any book on vibration test. These formulas are:

$$N = \frac{m^2 k}{2\pi L^2} \sqrt{\frac{E}{d}} \qquad \text{Equation 1}$$

$$E = \frac{473.3\ N^2 d L^4}{t^2\ m^4} \qquad \text{Equation 2}$$

N = Frequency of vibration (fundamental) in kilocycles.

E = Young's Modulus

D = Density of the beams in lbs./cu. ft.

L = Length of the beam in inches.

K = Radius of gyration of the section.

m = Constant depending on the mode of vibration.

R = $\frac{\text{Thickness}}{\text{Length}}$

Vibration in a beam produces two different movements: A motion of translation laterally and one of rotation relative to the position of the unbent neutral axis.[14]

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(14) T. C. Powers, Measuring Young's Modulus of Elasticity by Means of Sonic Vibration, American Society of Testing Materials, Proceedings, Vol. 38, Part 2, pp. 460-469, 1938.

In most of the cases the rotary inertia is neglected, but if the ratio of depth to length is not small the correction for rotary inertia must be applied as was the case in this thesis problem. The other correction to be made is correction for lateral inertia. It is proportional to Poissons ratio, which is taken as lb. for concrete. Both corrections may be applied at the same time by multiplying the ratio t/L by $(1 + 0.16)^{\frac{1}{2}}$ which is $\frac{4.5}{16}(1 + 0.16)^{\frac{1}{2}} =$ 0.302. The value for m is picked up from Figure 15, page 45, as 4.35.[15]

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(15) Ibid.

With corrections applied to equation 1 it becomes

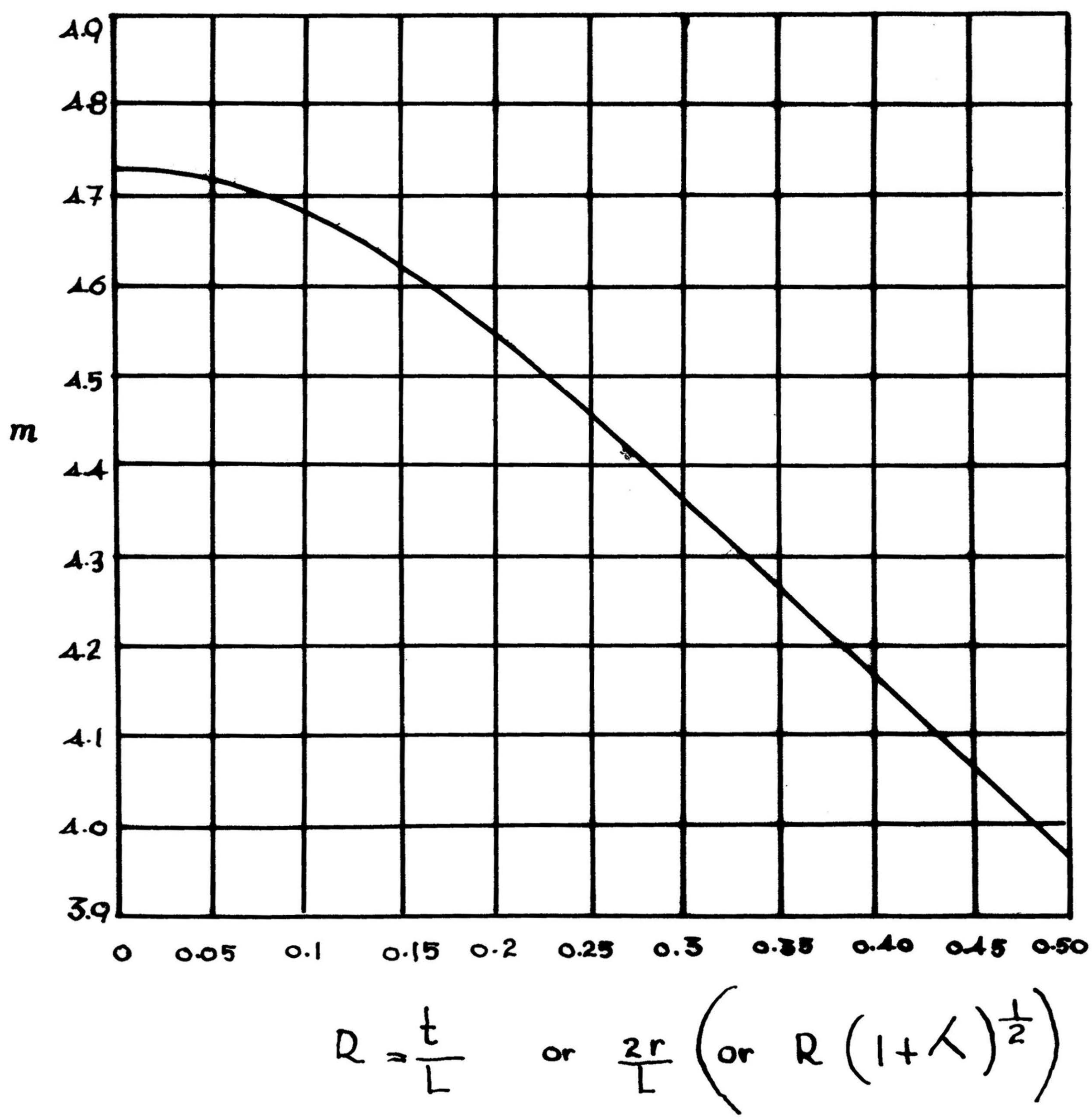
$$E = \frac{4\pi 2N2dL}{K^2(m)^4}$$

This equation is corrected for lateral and rotary inertia. When the values for the $3\frac{1}{2}$ inch by $4\frac{1}{2}$ inch by 16 inch beam are substituted, E value is obtained as $E = 6.35 \times 10^3 N^2 d$.

The first step in finding E is to obtain N by sonic apparatus. Test procedure is as follows.

Figure 15.

CURVE FOR DETERMINATION OF "m" IN SONIC APPARATUS



The concrete beams were supported at nodal points or .224L from the ends of the beams. The sonic machine was turned on and the pick up needle was placed on the middle. The beam was vibrated and the fundamental frequency was recorded. Then the needle was placed on the nodal point and the Torsional frequency was recorded as a check for fundamental frequency. The same procedure was followed for all the beams. Using fundamental frequency as N from above equation E was found.

Sonic testing of the beams were taken at the end of 20, 25, 30, 35 and 40 cycles. The results are shown on Table 4, pages 47, 48 and 49. Graph was also plotted showing air percentage against modulus of elasticity (see Figure 16, page 50).

Table 4

Twenty-eight Day Sonic Test Results

Cycle No.	Mix No.	Ave. Density in lbs. per cubic foot	Average Fundemental Frequency in Kilocycles per sec.	E in psi. x 10^6
	1	130	1.84	2.80
	2	133	1.82	2.79
	3	130	1.83	2.77
20	4	137	1.78	2.76
Cycles	5	135	1.82	2.84
	6	139	1.67	2.47
	7	139	1.57	2.18
	8	139	1.76	2.75
	1	130	1.79	2.65
	2	133	1.80	2.74
	3	130	1.70	2.39
25	4	137	1.76	2.70
Cycles	5	135	1.80	2.78
	6	139	1.61	2.29
	7	139	1.53	2.07
	8	139	1.72	2.61

Table 4
(cont.)

Twenty-eight Day Sonic Test Results

Cycle No.	Mix No.	Ave. Density in lbs. per cubic foot	Average Fundemental Frequency in Kilocycles per sec.	E in psi. x 10^6
	1	130	1.71	2.42
	2	133	1.79	2.70
	3	130	1.65	2.25
30	4	137	1.73	2.60
Cycles	5	135	1.78	2.72
	6	139	1.60	2.26
	7	139	1.41	1.75
	8	139	1.67	2.46
	1	130	1.61	2.14
	2	133	1.78	2.68
	3	130	1.59	2.08
35	4	137	1.68	2.46
Cycles	5	135	1.76	2.62
	6	139	1.55	2.12
	7	139	1.38	1.68
	8	139	1.65	2.40

Table 4
(cont.)

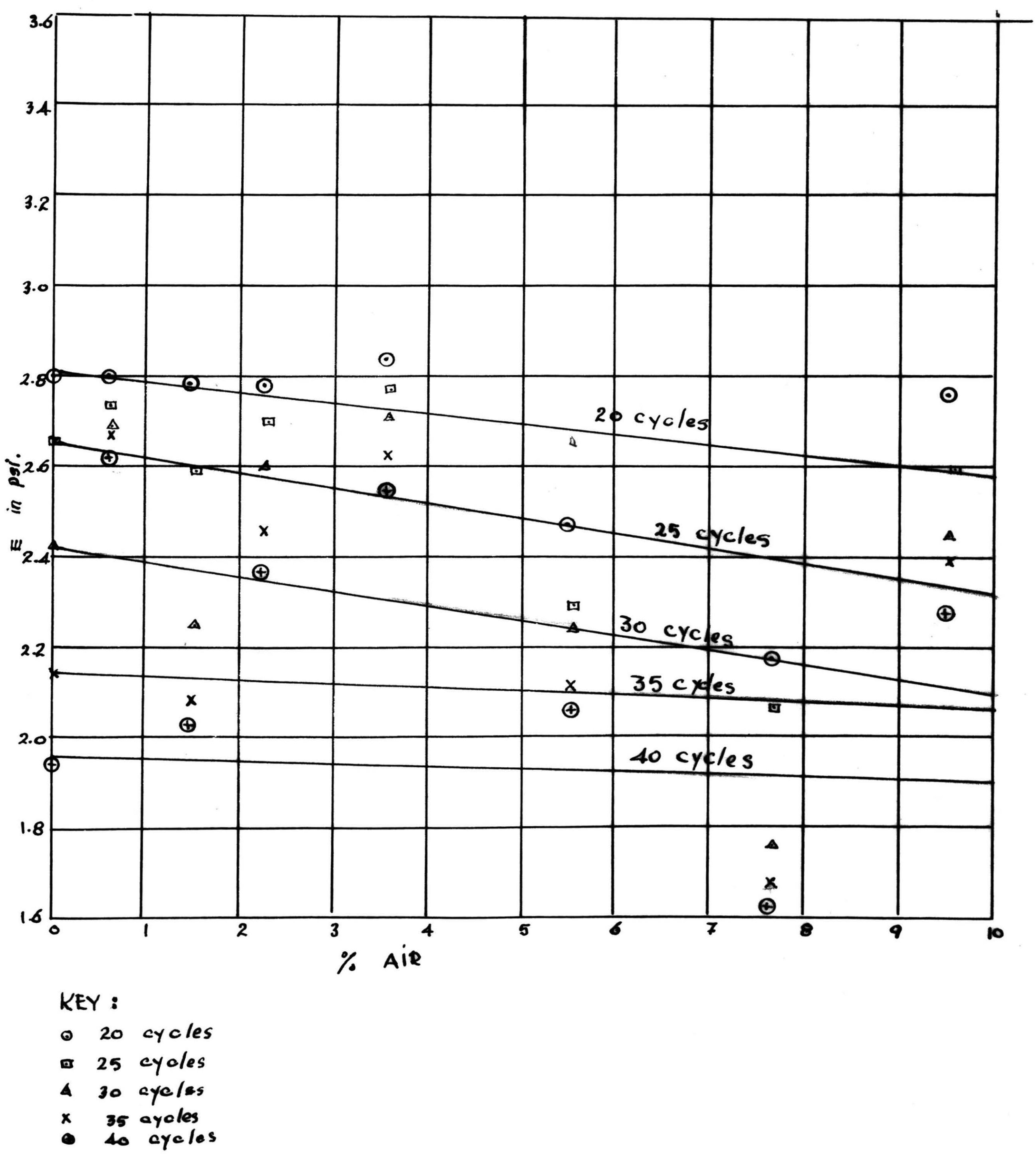
Twenty-eight Day Sonic Test Results

Cycle No.	Mix No.	Ave. Density in lbs. per cubic foot	Average Fundemental Frequency in Kilocycles per sec.	E in psi. x 10^6
	1	130	1.53	1.93
	2	133	1.76	2.62
	3	130	1.57	2.03
40	4	137	1.65	2.36
Cycles	5	135	1.73	2.56
	6	139	1.53	2.06
	7	139	1.36	1.63
	8	139	1.61	2.28

Figure 16.

CURVE OF AIRENTRAINMENT VS.

MODULUS OF ELASTICITY



CONCLUSIONS

Collaboration of the results obtained from the tests made throughout the experiments of this thesis with the results of the other authors' on the same subject was apparent. The conclusions drawn from those results will be listed in the following pattern.

1. No appreciable improvement in durability of concrete containing chert aggregate was caused by addition of vinsol resin to concrete to produce air-entrapment.

2. Air entrained mixes were more plastic and more workable than the mixes containing no air entrainment.

3. Although there were some exceptions, in most of the specimens the reduction in compressive strength with the increase in air percentage was apparent.

4. The density of the mix was decreased as air entrainment increased.

5. The modulus of elasticity was reduced with air entrainment but the effect of increasing air percentage on modulus of elasticity was not very noticeable.

6. The reduction in modulus of elasticity due to freezing and thawing cycles did not increase with the increase in air percentage.

7. Resistance to scaling and freezing and thawing was not apparent. The writer's explanation for this fact is the amount of cycles being limited due to the break down in the freezing machine.

8. Very dry cherts as used in these experiments yield concrete which initially resists failure during freezing and thawing. The absence of water in the cracks and pores of the chert, as indicated by the moisture test, indicates that a cause for failure of chert gravel concretes is due to the expansion of the retained moisture during freezing and thawing. If chert gravels are initially dry and can be mixed without water entering the gravel itself, the concrete is more resistant to disintegration than gravel fresh from the gravel pit.

The above conclusions show that to obtain a more definite answer to the problem which has been analyzed in this paper there is a need for more research to be done on this subject. In the present stage the results of Laboratory Tests on air entrainment and on freezing and thawing could be considered as indications rather than definite answers.

As the last conclusion the author would like to state that in his opinion there is only a slight chance that air entrainment in concrete containing chert aggregate will justify its use on highway pavements which are subjected to freezing and thawing throughout the year.

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VITA

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Since his father was serving as a Doctor in the Military Service at the time, his elementary schooling was received in schools located in different parts of Turkey. He graduated from the Lycee, which corresponds to the high school in America, in September, 1946, receiving a Baccalaureate Degree.

In January, 1947, he enrolled at the Engineering School of Robert College, which is an American Institute located at Bebek, Istanbul. After a semester of preparatory English courses, he started his studies in the Engineering School. He graduated from Robert College in June, 1951, receiving the degree of Bachelor of Science in Civil Engineering.

Upon graduation, he applied for acceptance for graduate work in the Civil Engineering Department at the Missouri School of Mines and Metallurgy. He was enrolled in the above mentioned school in September, 1951.

After acceptance of this thesis by the Graduate Committee of the Missouri School of Mines and Metallurgy, he will be eligible for the Master of Science Degree in Civil Engineering.